US Army Corps
of Engineers
North Central Division

Great Lakes Update

No. 107 June 3 , 1994

The Rise and Fall of the Great Lakes

Have you ever wondered why the water levels of the Great Lakes fluctuate over a range from as little as 2-1/2 feet to as much as 6-1/2 feet during high and low periods? With the recent attention focused on alleviating the adverse consequences of extreme water levels by the International Joint Commission's Levels Reference Study, a more in-depth discussion of why this happens is appropriate.

The Great Lakes have an enormous capacity to store water, with the lakes serving as reservoirs for the largest supply of standing fresh water in the world. The large surface area of the lakes acts as a natural regulator of their water levels. They discharge proportionately less water in prolonged dry periods and more water in times of cumulative water surplus. The present man-made control systems have only a small impact on the natural regulatory processes. Figure 1 shows the natural factors which affect the levels of the Great Lakes.

Additionally, the five lakes vary greatly from one another in both their geographic location and in their physical makeup. Size, depth, outflows, location in the chain, nature and configuration of shoreline and level of human intervention, all determine the levels of the lakes and the resulting impacts on the inhabitants of the basin.

The levels of the Great Lakes depend on the balance between the amount of water entering the lake and the amount of water leaving the lake. If these amounts remained exactly

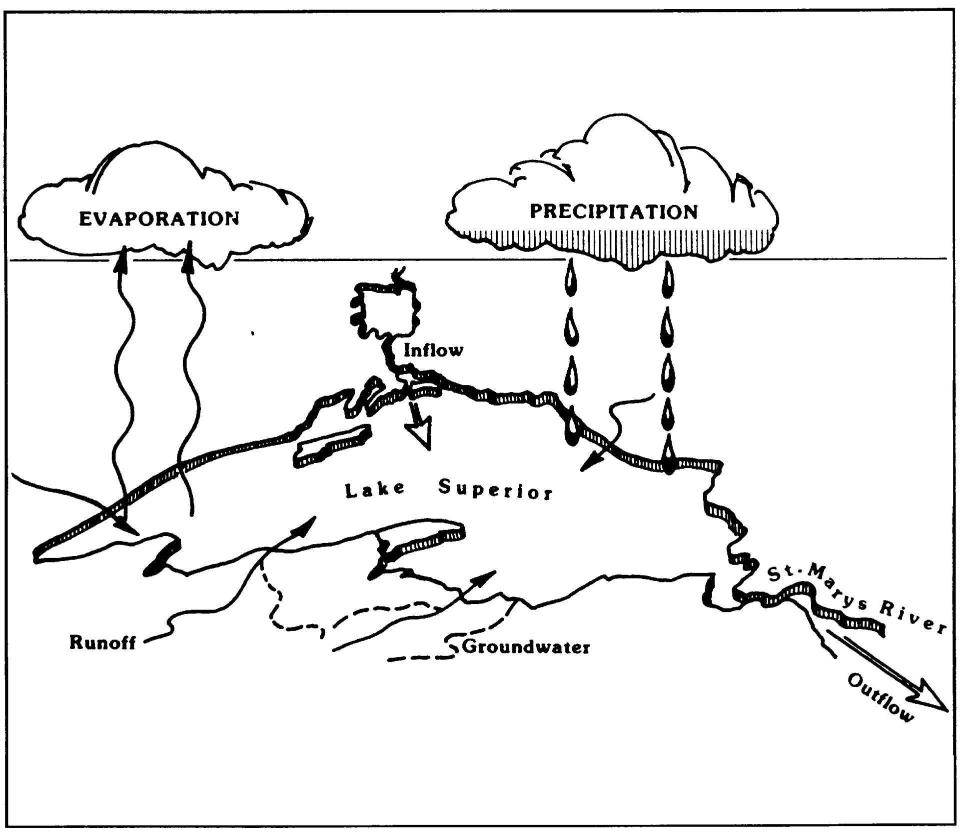

Figure 1. Natural Factors Affecting the Levels of the Great Lakes

the same, the general lake level would be constant. Whenever more water enters the lake than leaves it, the volume of water in the lake increases, causing the water level to rise. If less water enters the lake than leaves it, the opposite is true. This is readily observed in both the seasonal cycle, high summers/low winters, and longer term extreme trends.

The major factors affecting the fluctuation of lake levels are precipitation, evaporation, inflows and outflows. Other natural and artificial factors must also be taken into account, when determining the functioning of the natural system.

Natural Factors Affecting Lake Levels

The natural factors affecting each lake in the chain include the inflows from the upper lake, runoff from the land draining into that particular lake, ground water, precipitation falling directly on the water surface, evaporation from the lake surface and outflow to the next lower lake. Other natural phenomena which affect the water levels of the Great Lakes are ice in the connecting channels and St. Lawrence River, aquatic weed growth in these rivers, changes in barometric pressure, wind-induced waves, minor tides on the lakes, and crustal movement.

Precipitation is the primary source of input water for the Great Lakes basin. The average annual precipitation over the basin is 32 inches, with some variance between the Lake Superior area (30 inches) and the Lake Ontario area (35 inches). To illustrate how precipitation affects water levels, the latest high water period of the mid-1980s is used as an example. An eighteen-year period of above average precipitation, beginning in 1967, including the wettest year on record (1985 with an average of 40 inches) combined to cause the record high water levels of 1985 and 1986. Levels then declined rapidly in 1987, due largely to abnormally light precipitation from late 1986 to June 1987. This is illustrated in part in Figure 2 which shows the deviations from long-term average for Great Lakes basin precipitation for the period 1984-1988.

Runoff is the amount of water entering the lakes from precipitation falling on the land areas, and usually comes into the lakes over a period of time. On land, some of the precipitation enters into storage in small lakes swamps and streams; some moves through the soil; and, some accumulates in groundwater storage and becomes the source for springs and streams. Precipitation in the form of snow also has a distinct pattern of entry into these runoff systems. The rate of runoff is affected by a wide range of factors, including soil make-up and structure, the existing moisture levels of the soil, the rate of snow melt and the type of spring ice breakup in the tributary springs. Land use patterns, such as forest, agriculture and urban development also affect runoff, sometimes significantly.

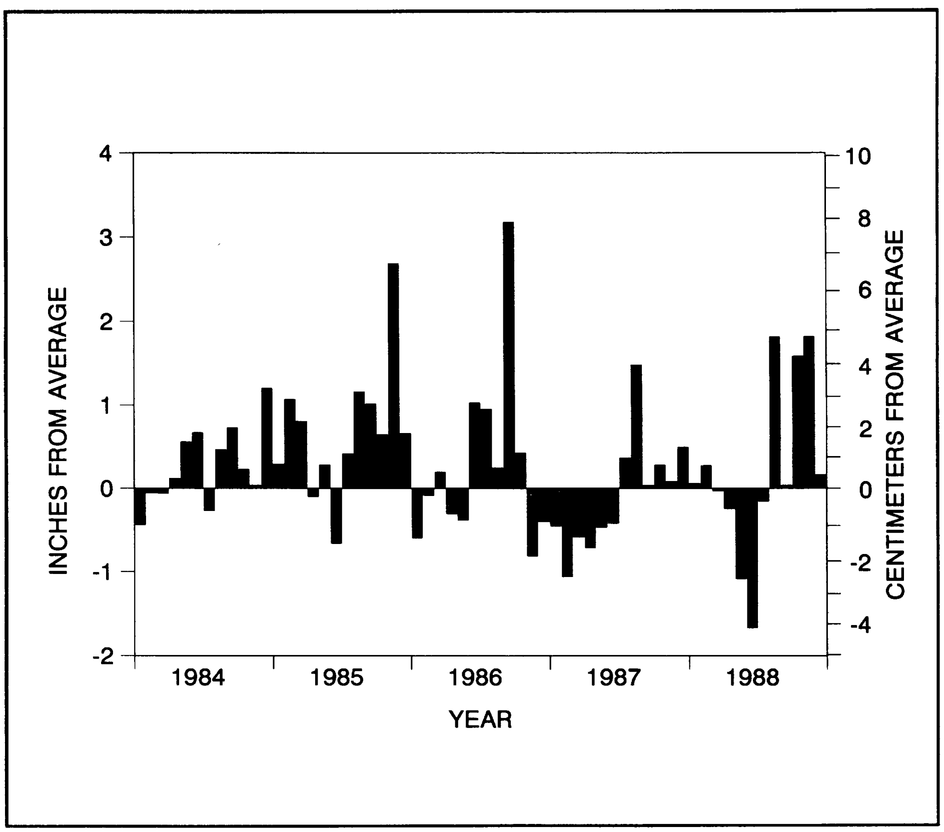

Figure 2. Great Lakes Monthly Precipitation (1984-1988) Deviation from Long-Term Average

Evaporation is the loss of water from the soil, vegetation or lake surface to the atmosphere. The rate of evaporation of water from the surfaces of the lakes can be estimated reasonably well. Proportionately more water evaporates from warm and shallow lakes, such as Erie, than it does from cold and deep lakes, such as Superior. Evaporation rates are quite variable over the course of each year due to changes in air and water temperature, wind speed, and "ambient" atmospheric moisture control, but remain relatively constant from year to year. Lake Erie's evaporation is estimated to be of similar magnitude to the precipitation which falls on it, while Lake Superior's evaporation is about one-half of the precipitation falling on that lake surface.

Climate also has a hand in determining the amount of water in the lakes as well as its behavior. One major climatic influence on lake levels is air temperature. At higher temperatures, evaporation and plant transpiration usually increase, resulting in less runoff; at lower air temperatures, given the same precipitation, the loss through evaporation and transpiration is generally less, and the runoff increases. Using Lake Erie as an example, in the 30 years from 1960 to 1989, the mean annual air temperature readings indicated a 0.8 degree Celsius drop. This resulted in a decrease in evaporation and an increase in runoff. The combined effect of an increase in precipitation, with this decrease in temperature, resulted in a 19% increase in runoff to the lake. As such, the high levels that occurred in the Great Lakes during the early 1970s to the mid-1980s were partly the result of the increased precipitation regime since 1940, coupled with the lower temperature regime since 1960.

Temporary flow restrictions in the connecting channels, often seasonally oriented, can cause short term increases in lake levels. Ice jams in the winter and early spring and excessive plant growth in shallow areas during the summer are the most common causes of these restrictions. During an ice jam on the St. Clair River, in April 1984, the flow was reduced by 40%. This reduction, while lasting only one month, resulted in a 0.19 foot rise in the level of Lakes Michigan-Huron, and a 2.12 foot and 0.70 foot drop in the levels of Lakes St. Clair and Erie, respectively.

Crustal movement refers to the continuing rebound of the earth's crust since the retreat of the glaciers. Basically, the entire Great Lakes basin is rising and tilting. Over time the water levels on the south and west shores will rise relative to levels on the north and east shores due to different rebound rates.

Artificial Factors Affecting Lake Levels

The artificial factors which affect Great Lakes water levels include the regulation of Lake Superior and Lake Ontario outflows, the diversion of water into, out of and between the Great Lakes basins, dredging in the connecting channels, and consumptive uses.

Regulation of Lakes Superior and Ontario has provided controls for the outflows of these two lakes since 1921 and 1958, respectively. The goal of the two regulation plans is to keep the lake levels within a specified range, near their long-term averages. The outflow controls are provided by a series of hydropower facilities, navigation locks, and gated control dams. The control of the outflows of these lakes allows the levels to be maintained within a smaller range than is possible without regulation.

Diversions of water which would not normally flow into and out of the system also affect lake levels. The Long Lac and Ogoki diversions bring water from northern Ontario's Albany River basin to Lake Superior, causing a small increase in lake levels due to the increased water supply. The Lake Michigan diversion at Chicago diverts a prescribed amount of water out of Lake Michigan into the Illinois Waterway and Mississippi River. The Welland Canal is principally an inter-lake connection, joining Lakes Erie and Ontario. Both of these diversions remove water from the Great Lakes system for the purposes of sanitation, power production and navigation. Combined, these four major diversions ultimately cause a net lowering of lake levels by decreasing the water supply to the lakes.

Dredging in the connecting channels of the Great Lakes increases their depths allowing them to carry more water. This increase in flow theoretically translates into a lowering of the levels of the upstream Lakes. Dredging has taken place in the St. Clair and Detroit Rivers since the early 1900s for the purposes of commercial extraction of gravel, and enlargement of the navigation channels for shipping. Some of the lowering effects of the upstream lakes due to dredging were offset by placing the dredged materials, or constructing retarding structures, in areas of the river where they do not impede navigation. This is known as compensation, and it helps to decrease the flow in the river and raise the levels of the upstream lakes to their natural condition. This was accomplished on the Detroit River, but not on the St. Clair River.

Consumptive use is that portion of water withdrawn from the Great Lakes system that is not returned. This includes water which is consumed by humans and animals, used for irrigation and municipal and rural water supplies, incorporated into manufactured products, and used during industrial processes. Consumptive use results in a slowly progressive lowering of the level of the lake from which it was taken and a consequent lowering of all unregulated lakes farther down the system.

All of these natural and artificial factors contribute to the three basic categories of water level fluctuations on the Great Lakes, described below: long-term, seasonal and short-term.

Long-Term Fluctuations

Long-term fluctuations usually take several years to manifest themselves, and often, as many years to restabilize. They are the result of persistent low or high water supply conditions within the basin, which culminate in extremely low levels, such as were recorded in the mid-1960s, or in extreme high levels such as those of the early to mid-1970s and mid-1980s. Figure 3 shows the long-term fluctuations of Great Lakes water levels from 1950-1990. The intervals between periods of high and low levels, and the lengths of such periods vary widely. More than 100 years of water level records on the Great Lakes indicates that there is no regular, predictable cycle. Because of the vast size of the Great Lakes and the limited discharge capacity of their outflow rivers, extremely high or low levels and flows can exist for a considerable time after the factors which caused them have changed, or ceased contributing to the situation.

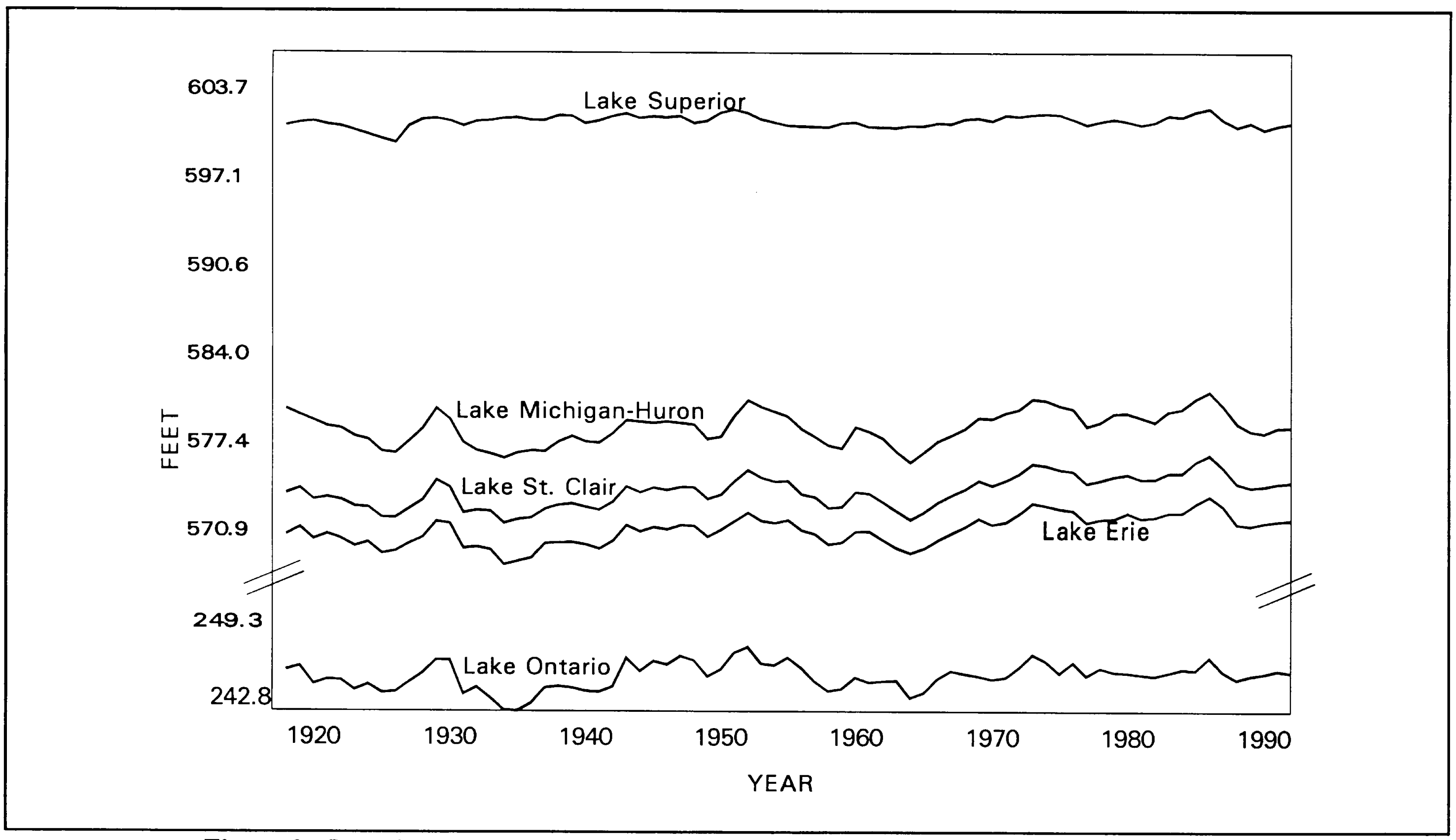

Figure 3. Long-Term Fluctuations Shown in Annual Average Great Lakes Water Levels

Seasonal Fluctuations

Seasonal fluctuations reflect the annual hydrologic cycle. In the early spring, as a result of snowmelt, heavier rains and reduced evaporation over the basin due to lower temperatures, the water levels begin to rise from their winter lows. This trend continues until the lakes peak, usually sometime in the summer. During the summer, when the lakes are their warmest, persistent winds and drier air intensify evaporation, and runoff and groundwater flow reach their lowest values. As the water supplied to the lakes become less than the outflows, the water levels begin their downward trend toward the winter minimums. These seasonal fluctuations are shown in Figure 4 which depicts the monthly mean levels of each of the Great Lakes.

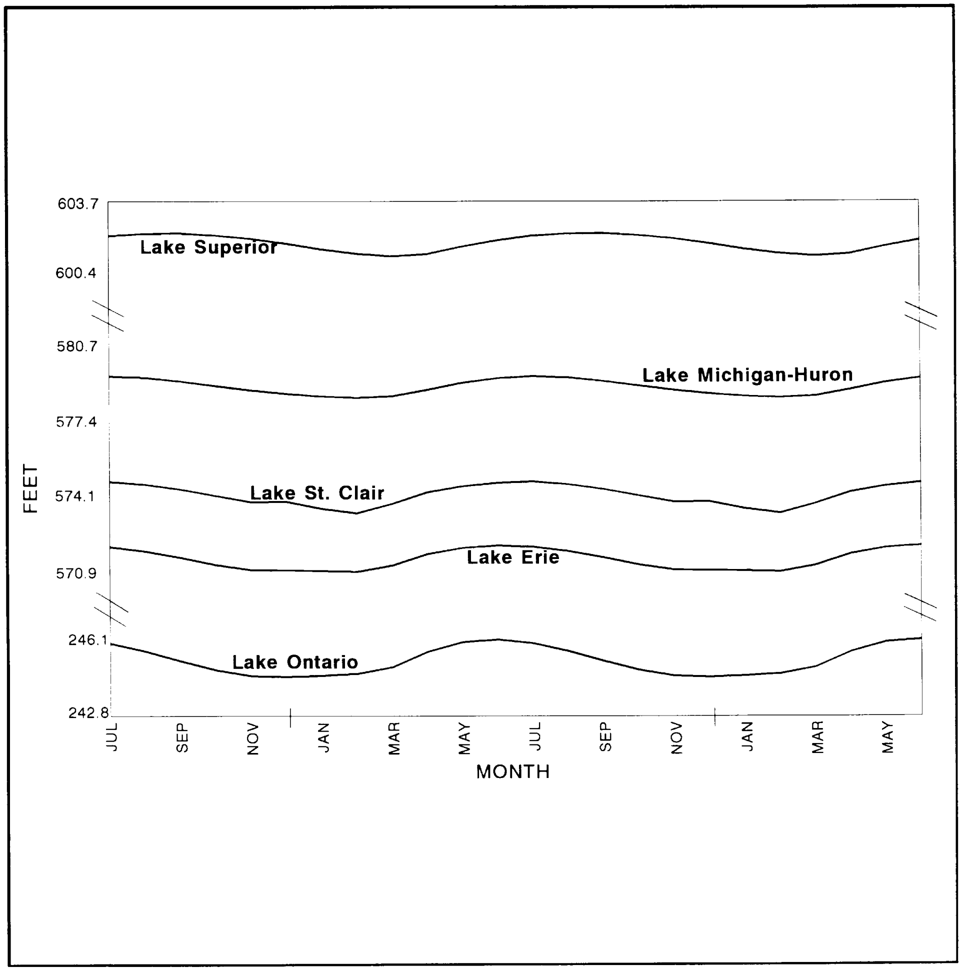

Figure 4. Seasonal Fluctuations Shown in Monthly Mean Great Lakes Water Levels

Short-term Fluctuations

The most dramatic changes in water levels are the short-term fluctuations caused by strong winds and/or by sudden changes in barometric pressure over different sectors of a lake. These fluctuations usually last less than one day, and do not represent any change in the volume of water in the lake. The strong wind and/or difference in barometric pressure can cause the lake surface to tilt, as shown in Figure 5.

Extreme examples of this phenomenon occur on Lake Erie, where, at times, sustained high winds along the length of the lake (which is aligned in the direction of the prevailing winds) causes the water level to rise substantially, while the level falls at the other end. One memorable event occurred on December 2, 1985, when the difference in water levels, due to wind set-up between Buffalo, New York and Toledo, Ohio was almost 16 feet, as shown in Figure 6.

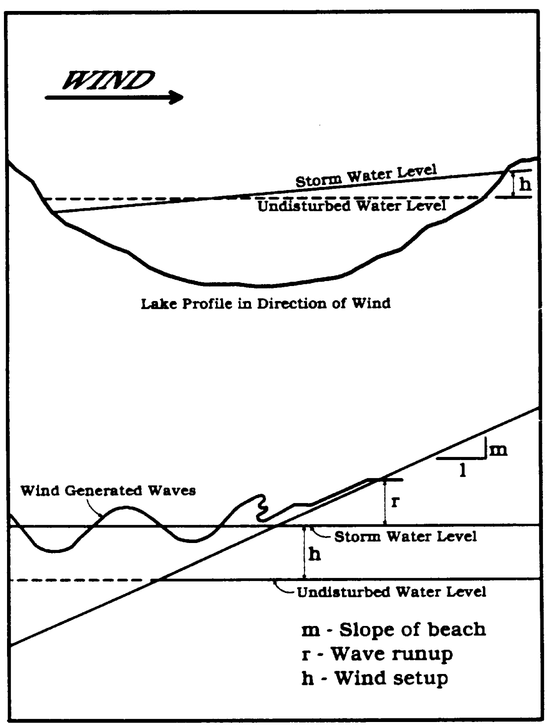

Figure 5. Wind Effects on Lake Levels

Other short-term fluctuations in lake levels may be caused by intense rain storms, barometric surges, or by ice jams in the connecting channels.

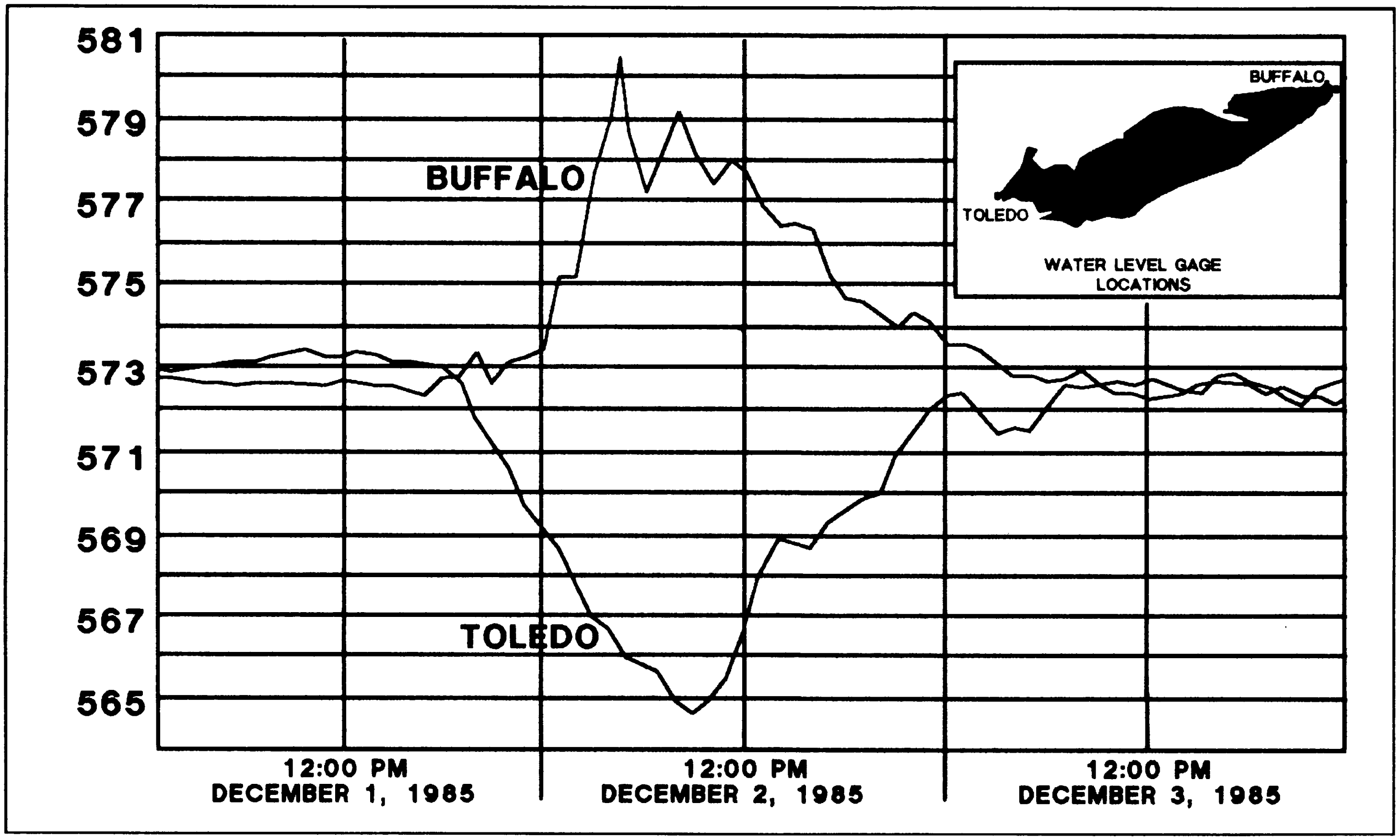

Figure 6. Wind Set-up Between Buffalo, NewYork and Toledo, Ohio on December 2, 1985

Summary

As described herein, the fluctuation of water levels on the Great Lakes are the result of many factors. Natural factors affecting the lake levels include precipitation, runoff and evaporation, among others. Artificial factors, including regulation of Lakes Superior and Ontario, diversions into and out of the basin and dredging also affect lake levels to a lesser degree. The three types of water level fluctuations on the Great Lakes, long-term, seasonal and short-term, also have an affect on high and low water levels and their timing through the year. Seasonal fluctuations reflect the annual hydrologic cycle and are fairly consistent, while long-term fluctuations are unpredictable.

The fluctuations of the Great Lakes water levels affect many different interests, from people living along the shoreline, recreational boaters and naturalists, to commercial shippers and hydroelectric power producers. These fluctuations have existed since the Great Lakes were formed by the retreating glaciers, and will continue to exist for many years in the future.

Meetings With the Public

As noted last month, the International Lake Superior Board of Control (Lake Superior Board) and the International St. Lawrence River Board of Control (St. Lawrence Board) are holding meetings with the public this month. The meetings are to inform the public of the Board's responsibilities and current activities and to hear your comment: and suggestions. The times and locations of each meeting are:

Lake Superior Board:

June 14, from 7:30 to 10:00 p.m.
Canal Park Museum
600 Lake Avenue South
Foot of Canal Park Drive
Duluth, Minnesota

St. Lawrence Board:

June 21, from 7:30 to 10:00 p.m.
Captain's Quarters Hotel
26 East 1st Street
Oswego, New York

RICHARD W. CRAIG
Colonel, EN
Commanding

Table 1

Possible Storm Induced Rises (in feet) at Key Locations on the Great Lakes
June 1994

	Degrees of Possibility				
	20%	10%	3%	2%	1%
LAKE SUPERIOR					
Duluth	0.7	0.8	0.8	0.9	0.9
Grand Marais	0.5	0.6	0.8	0.9	1.0
Marquette	1.2	1.5	1.9	2.1	2.4
Ontonagon	0.7	0.9	1.2	1.5	1.7
Point Iroquois	0.8	0.9	1.0	1.1	1.2
Two Harbors	0.7	0.9	1.1	1.3	1.6
LAKE MICHIGAN					
Calumet Harbor	1.3	1.5	1.8	1.9	2.1
Green Bay	1.6	1.8	2.1	2.4	2.6
Holland	0.6	0.7	0.7	0.8	0.8
Kewaunee	0.8	0.9	1.0	1.1	1.2
Ludington	0.7	0.8	0.9	1.0	1.0
Milwaukee	1.0	1.1	1.3	1.5	1.6
Port Inland	1.0	1.2	1.4	1.6	1.8
Sturgeon Bay	0.7	0.8	1.0	1.1	1.2
LAKE HURON					
Detour Village	0.5	0.5	0.6	0.6	0.7
Essexville	1.4	1.6	1.9	2.0	2.2
Harbor Beach	0.7	0.8	1.0	1.1	1.2
Harrisville	0.6	0.7	0.8	0.9	0.9
Lakeport	0.8	1.0	1.3	1.6	1.8
Mackinaw City	0.7	0.7	0.8	0.9	0.9
LAKE ST. CLAIR					
St. Clair Shores	0.4	0.5	0.6	0.6	0.7
LAKE ERIE *					
Barcelona	1.1	1.3	1.5	1.6	1.7
Buffalo	2.1	2.4	2.8	3.1	3.3
Cleveland	1.1	1.3	1.6	1.8	2.0
Erie	1.0	1.1	1.3	1.3	1.4
Fairport	0.8	0.8	0.9	1.0	1.0
Fermi Power Plant	1.3	1.6	2.0	2.3	2.6
Marblehead	1.1	1.3	1.5	1.7	1.9
Sturgeon Point	1.4	1.6	1.9	2.1	2.3
Toledo	1.9	2.2	2.7	3.0	3.3
LAKE ONTARIO					
Cape Vincent	0.5	0.6	0.8	0.9	1.0
Olcott	0.3	0.4	0.6	0.7	0.9
Oswego	0.5	0.6	0.8	0.9	1.0
Rochester	0.5	0.6	0.7	0.7	0.8

* The water surface of Lake Erie has the potential to tilt in strong winds, producing large differentials between the ends of the lake.

Note: The rises shown above, should they occur, would be in addition to the still water levels indicated on the Monthly Bulletin. Values of wave runup are not provided in this table.

Great Lakes Basin Hydrology

During the month of May precipitation on each Great Lakes basin was below average, with the exception of Lake Ontario which was above average. For the year to date, precipitation is about 7% below average for the entire Great Lakes basin. The net supply of water to Lakes Superior, Michigan-Huron and Erie was below average in May, while Lake Ontario was abov average. Table 2 lists May precipitation and water supply information for all of the Great Lakes.

In comparison to their long-term (1918-1993) averages, the May monthly mean water level of Lake Superior was at its long-term average, Lakes Michigan-Huron, St. Clair, Erie and Ontario were 7, 10, 10 and 4 inches above average respectively. Shoreline residents on Lakes Michigan-Huron, St. Clair and Erie are cautioned to continue to be alert to possible adverse weather conditions, as these could compound an already high lake level situation. Further information and advice will be provided by the Corps of Engineers should conditions worsen.

TABLE 2
GREAT LAKES HYDROLOGY[1]

PRECIPITATION (INCHES)								
BASIN	MAY				YEAR-TO-DATE			
	1994[2]	Average (1900-1991)	Diff.	% of Average	1994[2]	Average (1900-1991)	Diff.	% of Average
Superior	2.4	2.7	-0.3	89	9.2	9.8	-0.6	94
Michigan-Huron	2.4	3.0	-0.6	80	10.3	11.5	-1.2	90
Erie	2.1	3.3	-1.2	64	12.7	13.7	-1.0	93
Ontario	3.4	3.1	0.3	110	14.2	13.6	0.6	104
Great Lakes	2.5	3.0	-0.5	83	10.8	11.6	-0.8	93

LAKE	MAY WATER SUPPLIES[3] (CFS)		MAY OUTFLOW[4] (CFS)	
	1994[2]	Average (1900-1989)	1994[2]	Average (1900-1989)
Superior	159,000	186,000	87,000	75,000
Michigan-Huron	174,000	251,000	195,000[5]	189,000
Erie	27,000	46,000	234,000[5]	213,000
Ontario	63,000	60,000	283,000	257,000

[1]Values (excluding averages) are based on preliminary computations.
[2]Estimated.
[3]Negative water supply denotes evaporation from lake exceeded runoff from local basin.
[4]Does not include diversions.
[5]Reflects effects of ice/weed retardation in the connecting channels.

CFS = cubic feet per second.

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